Foot strike patterns in runners wearing floating heel, minimalist and conventional footwear

BARNES, Andrew <http://orcid.org/0000-0001-8262-5132>, PAYA, Javier Gamez, CASTELLI, Andrea and HELLER, Ben <http://orcid.org/0000-0003-0805-8170>

Published version

BARNES, Andrew, PAYA, Javier Gamez, CASTELLI, Andrea and HELLER, Ben (2015). Foot strike patterns in runners wearing floating heel, minimalist and conventional footwear. 33rd International conference on biomechanics in sports, 2015, 519-522.

FOOT STRIKE PATTERNS IN RUNNERS WEARING FLOATING HEEL, MINIMILIST AND CONVENTIONAL FOOTWEAR.

Andrew Barnes[1], Javier Gamez Paya, Andrea Castelli[3], Ben Heller [2],

[1]Academy of Sport and Physical Activity, Sheffield Hallam University, Sheffield, UK
[2]Centre for Sports Engineering Research, Sheffield Hallam University, Sheffield, UK
[3]Department of Information Engineering, University of Sassari, Sassari, Italy

The purpose of this study was investigate the vertical loading rate and footstrike angles when running in floating heel shoes (a new concept called FBR (Faster and Better Runners) compared to conventional and minimalist shoes. Footstrike angle and force data were collected from 15 male recreational runners as they ran in three different footwear conditions, floating heel, conventional and minimalist shoes. Results revealed that running in floating heel shoes promotes a non-rearfoot strike and results in reduced vertical loafing rates compared to both conventional and minimalist footwear. These findings suggest that floating heel shoes may offer a new way of running with a non-rearfoot strike without the risk of impact related injuries.

KEYWORDS: Vertical loading rate, Ground reaction force, Foot strike angle.

INTRODUCTION: Overuse injuries in runners represent a significant problem, injury rates have been reported to range between 19-79%, with the lower extremity most at risk (Van Gent et al., 2007). The impact associated with footstrike is thought to be an important factor related to several overuse injuries, with vertical loading rate being linked to injuries including stress fracture (Milner, Hamill and Davis, 2006;), patellofemoral pain (Cheung and Davis, 2011) and plantar fasciitis (Pohl, Hamill and Davis, 2009). Understanding running mechanics in relation to injury risk factors represents an important step in designing interventions aimed at reducing the incidence of overuse injuries in the running population. Modifying footwear properties has long since been a focus for running shoe designers, with traditional approaches focussing on the concepts of shock attenuation and motion in an attempt to alter the loading profile of runners (Nigg, 2001). Despite several decades of running shoe development aimed at reducing injuries, the incidence of overuse injuries has remained relatively unchanged (Buist et al., 2010).

Footstrike pattern is one variable that has been suggested to affect injury rates. Daoud et al. (2012) found that rearfoot strikers were 2.5 times more likely to experience a moderate repetitive stress injury than non-rearfoot strikers. A non-rearfoot pattern has been found to decrease vertical loading rates compared to a rearfoot strike (Lieberman et al., 2010). This evidence suggests that adopting a midfoot or forefoot running style may reduce the likelihood of overuse injury. Recent evidence has found that rearfoot strikers who switched to a non-rearfoot strike pattern had reduced peak vertical loading rates (Delgado et al., 2013).

In recent years, running in minimalist footwear has received growing attention with the Vibram FiveFingers found to reduce running economy compared to running barefoot and in conventional footwear (Squadrone & Gallozzi, 2009). Furthermore, running in Five Fingers has been found to reduce impact forces when compared to conventional shoes (Squadrone & Gallozzi, 2009). However, some limited evidence suggests that running in minimalist shoes increases the likelihood of a metatarsal stress fractures (Salzer et al., 2012).

A new floating heel running shoe concept called FBR (Faster and Better Runners) has been designed which promotes a non rearfoot contact and allows free movement of the heel without any ground contact during stance (patent Nº ES1099206). The floating heel has been designed to allow runners to take more advantage of energy storage and elastic recoil in the achilles tendon longitudinal arch of the foot. A further feature of the footwear is a cushioning element under the midfoot and forefoot in line with that seen in conventional footwear.

Therefore, the floating heel running shoe may offer reduced impacts compared to minimalist footwear, while still promoting a non-rearfoot strike pattern.
The purpose of this study was investigate the vertical loading rate, contact time and footstrike angles when running in floating heel shoes compared to conventional and minimalist shoes. It was hypothesised that running in floating heel shoes would promote a non-rearfoot strike pattern and an associated reduction in contact time and vertical loading rates when compared to conventional and minimalist shoes.

METHODS: After ethics approval, 15 male participants (age 40.1 ± 10.9 years; height 1.79 ± 0.06 m; mass 78.2 ± 9.1 kg) gave informed consent to take part in the study. All participants were recreational runners currently free from injury who ran at least 20 Km per week and had a 5 Km personal best time of below 24 minutes. All those recruited were habitually rearfoot strikers, confirmed using high-speed sagittal plane video recording at 100Hz.
This study compared three different footwear conditions; conventional running shoes (CVN) (IPSO Vento by SPRINTER), minimalist running shoes (BFT) (Vibram Five Fingers) and floating heel shoes (FHS) (FBR Footwear). All participants completed a three week habituation period consisting of eight sessions to become accustomed to running in the different types of footwear. The programme consisted of a mixture of treadmill and overground running, beginning with 2 runs of 8 minutes in each footwear condition in week one (-30% 5Km personal best time), increasing to 3 runs of 12 minutes by week three (-10% 5Km personal best time). Participants were required to maintain their normal training schedule wearing their own usual footwear. The habituation protocol purposefully did not offer participants specific instruction on how to run, but asked them to run in a manner that felt comfortable. This approach allowed us to evaluate the footstrike mechanics associated with running naturally in each of the footwear conditions.
Following a short warm up, all participants performed 5 good running trials over a force plate (Kistler, 9281CA, Winterthur, Switzerland) sampling at 1000Hz. Participants ran along a 16m runway at their 5km personal best time (within 5%) in all three footwear conditions (completed in a random order), this was monitored using three sets of timing gaits (Brower Timing Systems, Draper, UT, USA) along the runway. A good trial was determined if a constant speed was maintained along runway and a right foot contact made with the force platform without apparent gait alteration - determined through visual inspection by the investigator. Three-dimensional marker data (Motion Analysis Corporation, Santa Rosa, USA) were collected for two markers placed on the right shoe over the head of the 2nd metatarsal and the inferior calcaneus.
Kinematic and kinetic data were cropped to the stance phase using the ground reaction force data (15N threshold). Foot strike angle (FSA) was defined as the angle at initial contact between the anterior posterior axis of the laboratory and a vector between the inferior calcaneus and 2nd metatarsal marker (Altman & Davis 2012). A positive FSA was more indicative of a rearfoot strike and a negative FSA was more indicative of a forefoot strike. Average vertical loading rate (AVLR) was calculated as the change in force divided by time across the 20-80% of the peak. Instantaneous vertical loading rate was calculated as the peak point to point loading rate during the initial loading phase. All loading rates were normalised to body weight. Variables were calculated based on 5 running cycles for each of the three time conditions. ANOVA with post hoc Bonferroni tests was used to determine differences in dependent variables between conditions for each group ($p<0.05$).

RESULTS: Visual inspection of both vertical ground reaction force traces and the FSA data revealed three distinct subgroups of participants, those who displayed a rearfoot strike when running in CVN but a non-rearfoot pattern when running in both BFT and FHS (group 1, n = 6), those who displayed a non-rearfoot pattern in all three footwear conditions (group 2, n = 4)) and those who displayed a rearfoot strike when running in both CVN and BFT, but a non-rearfoot pattern when running with FHS (group 3, n= 5)). As such, these subgroups were analysed separately. For contact time, in both groups 1 and 2 contact time was greater when running CVN compared to both BFT and FHS (Table 1). Importantly, no differences were seen in contact time between BFT and FHS. Large differences were seen in FSA across conditions. In group 1, both BFT and FHS displayed lower FSA when compared to CVN, while in group 3 FSA was lower compared to both BFT and CVN (Table 1).

Table 1 Group means (SD) for contact time and FSA in each footwear condition.

Group	Contact time (ms)			FSA (°)		
	CVN	BFT	FHS	CVN	BFT	FHS
group 1	244(38) #	226(31)	233(32)*	31.0(7.2)#	-1.5(7.5)~	4.0(10.3)*
group 2	198(11)#	187(11)	190(12)*	10.5(6.9)	-0.7(8.8)	4.9(10.7)
group 3	215(24)	212(29)	211(20)	25.3(7.7)#	20.3(6.6)~	-2.4(7.1)*

Difference between CVN and BFT. ~ Difference between BFT and FHS. * Difference between CVN and FHS.

Loading rates were seen to differ across conditions for all three groups (Table 2). In group 1, AVALRs and IVLRs were found to be lower when running in FHS compared to both CVN and BFT footwear. For group 2, lower AVLR's were seen for both BFT and FHS compared to CVN. No differences were seen for either variable between FHS and BFT. In group 3, both AVLR and IVLR were found to be lower in FHS and CVN compared to BFT (Table 2).

Table 2 Group means (SD) for AVLR and IVLR in each footwear condition.

Group	AVLR (BW/s)			IVLR (BW/s)		
	CVN	BFT	FHS	CVN	BFT	FHS
group 1	95.2 (18.3)#	59.9(11.4)*	48.9(11.40)~	56.1(14.3)#	50.0(5.4)~	43.2(9.3)*
group 2	95.7(18.8)#	73.1(12.7)	70.6(9.7)*	60.5(9.7)	62.2(11.4)	57.9(6.9)
group 3	129.7(47.1)#	269.3(49.2)~	96.6(32.4)	68.6(15.9)#	133.6(17.3)	75.4(34.4)*

Difference between CVN and BFT. ~ Difference between BFT and FHS. * Difference between CVN and FHS.

DISCUSSION: The purpose of this study was investigate footstrike angle, contact time and vertical loading rates when running in floating heel shoes (FBR footwear) compared to conventional and minimalist shoes. Interestingly three sub groups of runners who displayed distinct footstrike patterns were observed. Runners in group 1 adopted a non-rearfoot strike pattern when running barefoot and in floating heel shoes while runners in group 2 adopted a non-rearfoot pattern in all three conditions. Given that all runners were heelstrikers prior to the study, the results for group 2 suggest that these individuals changed their running technique during the 3 week habituation period with no training. Finally group 3 ran with a non-rearfoot pattern in floating heel shoes but a rearfoot strike pattern when barefoot. These findings are in line with those of Lieberman et al. (2010), who found that habitually shod runners also displayed a rearfoot strike pattern when barefoot but adopted a flatter foot placement by 7-10°. This suggests that the transition to running in minimalist footwear could cause injuries as some runners fail to adapt their running technique. Importantly, in all three groups a non-rearfoot pattern was observed when running in floating heel footwear.
For groups 1 and 2, shorter contact times were seen when running in barefoot and floating heel shoes compared to conventional footwear, but no differences were seen between barefoot and floating heel shoes. This suggests that running in floating heel shoes more closely replicate ground contact times seen when running barefoot than in conventional footwear. The differences in footstrike angles between conditions caused markedly different vertical loading rates. In group 1, average loading rates were found to be considerably lower when running in floating heel shoes compared to both conventional (49%) and minimalist footwear (18%). This trend was also evident in group 2, who despite running with a non-rearfoot strike in all three conditions displayed lower average loading rates (26%) when running in floating heel shoes compared to conventional footwear. These data support recent evidence which found that rearfoot strikers who switched to adopting a non-rearfoot strike pattern had reduced peak vertical loading rates (Delgado et al., 2013). Findings suggest that floating heel shoes not only promote a non-rearfoot strike but also reduce vertical loading

rates compared to conventional and minimalist shoes. In group 3 loading rates were significantly reduced when running in floating heel shoes compared to both conventional and minimalist footwear. These findings suggests that for some habitually rearfoot strikers who fail to adapt their footstrike in minimalist shoes, running in floating heel shoes results in a non-rearfoot pattern and reduced loading rates. Therefore, floating heel footwear may result in a new way of running to support runners with the transition to a non-rearfoot strike.
The present study used both vertical force traces (evidence of an initial impact peak) and the FSA to categorise runners as either rearfoot or non-rearfoot strikers in different footwear conditions. Altman and Davis (2012) defined a FSA of < -1.6° as a forefoot strike, a FSA of between -1.6° and 8.0° as a midfoot strike and a FSA of > 8.0° as a rearfoot strike. In groups 1 and 2 of the present study, some runners in the floating heel shoe condition displayed a FSA of > 8.0°. Similarly two of the subjects categorised in group 2 had FSA of > 8.0°.While these differences may suggest a rearfoot strike according to the classification of Allison, Altman and Davis (2012), all these runners displayed vertical ground reaction force traces consistent with a non rearfoot strike. These differences may have occurred as the floating heel shoe condition permits free movement of the heel allowing a midfoot initial contact but with the ankle in a more dorsiflexed position.

CONCLUSION: This study suggest that floating heel shoes promote a non-rearfoot strike pattern and reduced vertical loading rates compared to conventional and minimalist shoes. Floating heel footwear offers a new way of running with a non-rearfoot strike and may also support those runners looking to transition to a non-rearfoot strike without the risk of impact related injuries. However, further investigation of the kinematic and kinetic profile associated with running in floating heel shoes.

REFERENCES:

Altman, A.R & Davis, I.S. (2012). A kinematic method for footstrike pattern detection in barefoot and shod runners. *Gait and Posture*, 35, 298-300.
Buist, I., Bredeweg, S.W., Bessem, B., et al. (2010). Incidence and risk factors of running-related injuries during preparation for a 4-mile recreational running event. *British Journal of Sports Medicine*, 44, 598-604.
Cheung, R.T. & Davis, I.S. (2011). Landing pattern modification to improve patellofemoral pain in runners: a case series. *Journal of Orthopaedic Physical Therapy*, 41,914-919.
Daoud, A.I., Geissler, G.J., Wang, F. et al. (2012). Foot Strike and Injury Rates In Endurance Runners: A Retrospective Study. *Medicine Science in Sports and Exercise,* 44, 1325-34.
Delgado, T.L., Kubera, E., Robb, R.R. et al. (2013). Effects of foot strike on low back posture, shock attenuation, and comfort in running, *Medicine Science in Sports and Exercise*, 45,490-6
Lieberman, D.E., Venkadesan, M., Werbel, W.A. et al. (2010). Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature,* 463, 531-536.
Milner, C.E. Ferber, R. Pollard, et al. (2006). Biomechanical factors associated with tibial stress fractures in female runners. *Medicine Science in Sports and Exercise,* 38, 323-328.
Nigg, B.M. & Wakeling, J. (2001). Impact Forces And Muscle Tuning: A New Paradigm. *Exercise and Sports Science Reviews*, 29, 37.
Pohl, M.B. Hamill, J. & Davis, I.S. (2009). Biomechanical and anatomical factors associated with a history of plantar fasciitis in female runners. *Clinical Journal of Sports Medicine*, 19, 372-376.
Salzer, MJ. Bluman, EM. Noonan, S. et al. (2012). Injuries observed in minimalist runners. *Foot and Ankle International*, *33*, 262-266. Shih, Y. Lin, K.L., & Shiang, T.Y. (2013). Is the foot striking pattern more important than barefoot or shod conditions in running? *Gait and posture*, *38*, 490-494.
Squadrone, R. & Gallozzi, C. (2009). Biomechanical and physiological comparison of barefoot and two shod conditions in experienced barefoot runners. *Journal of Sports Medicine and Physical Fitness,* 49, 6-13.
Van Gent, R. Siem, D. Van Middelkoop, M. et al. (2007). Incidence and Determinants Of Lower Extremity Running Injuries In Long Distance Runners: A Systematic Review. *British Journal of Sports Medicine,* 41, 469-480.

Acknowledgement
The research team would like to thank the inventor of FBR running shoes Mr. Francisco Beneyto Abad as well as SPRINTER Sport & Style for their support throughout this study.